Comprehensive Marine Particle Analysis System

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LONG-TERM GOAL

The long term goal is development and utilization of a comprehensive (broadly capable) marine particle analysis system. The system is designed with wide dynamic range, thus, it will ultimately be used for high speed, high resolution characterization of water column particle fields in high, medium and low latitudes. As part of a broader goal this project continues advancement of the AOSN concept through joint use of both towed platforms and autonomous underwater vehicles.

OBJECTIVES

The project's objective is to develop a comprehensive marine particle analysis system, which, along with other sensor systems, will enable us to address basic oceanographic, environmental and ultimately military issues. The objective includes adapting sensors to towed platforms and AUVs to characterize particle fields in a variety of oceanic environments.

APPROACH

The high resolution sampler (HRS) is designed to measure ocean properties that will provide insight into water column chemical, physical and biological processes. The platform has been used in Gulf of Mexico deployments to gather meaningful data and show efficacy. The approach for this project is to complete the sensor prototypes initiated in the period 1994 to 1999; test them at the USF Center for Ocean Technology (COT); sea-test them on the HRS towed platform; and then adapt sensors, as available, to Florida Atlantic University AUVs. Deployments of the HRS in the Gulf of Mexico and

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deployments on AUV/ROVs are part of this project. Acquired data will allow researchers access to an enhanced data set for improvement and advancement of their models.

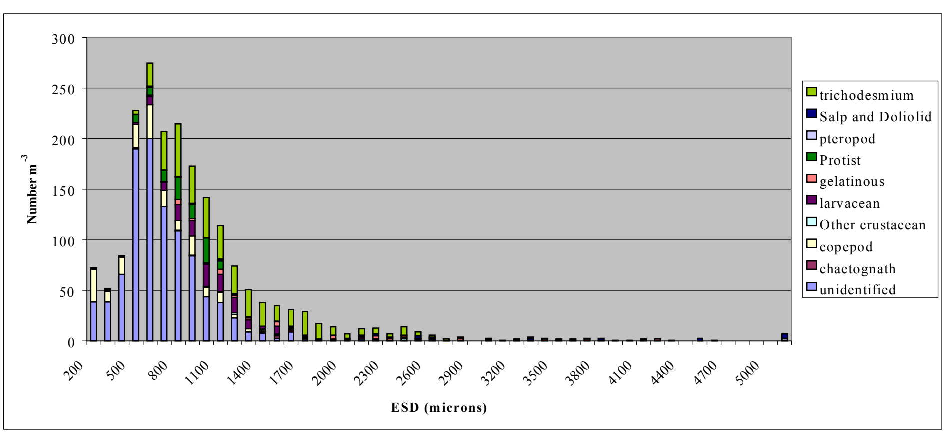
WORK COMPLETED

i. Shadowed Image Particle Profiling and Evaluation Recorder (SIPPER)

The SIPPER instrument has been developed to accurately evaluate particle concentrations in a wide range of sizes, by providing as its output high-quality thresholded binary images. This instrument is uniquely capable of completely imaging particles from several tens of microns through several centimeters in length, from two directions [1-3].

Progress on SIPPER is being done in stages to permit improvements in the existing instrument and allow optimization of the various system components. The SIPPER electronics have been modified from the prototype to improve the quality of the thresholded binary images. The improvements account for spatial variation in illumination. With the improved image quality, high-level software analysis (automated sizing, manual identification) are greatly simplified. A commercial image processing package (OPTIMAS) has been utilized to allow semi-automated particle size calculations to be made. The hardware in conjunction with simplified control software improvements allows operation in water of varying particle loads, with minimal user-intervention. Data storage has been increased from 40 to 105 minutes with the use of a 50 GB storage drive. Digital data offload can be achieved more quickly through a 100 Mbits/second Ethernet connection, which reduces turnaround time before SIPPER can be re-deployed.

SIPPER images, once collected and transferred to a shipboard PC, are analyzed for particle sizing and identification. This is done through the use of two software packages: SIPPERView and OPTIMAS. The former has been developed in-house to allow the user to immediately view located particles from two orthogonal directions, and save captured images to a standard PC file format (.bmp. The second application, OPTIMAS, is a commercial packaged developed to properly scale, display and analyze images. OPTIMAS has an extensive image processing library, and macro capability, which allows for automated particle property extraction (length, width, equivalent spherical diameter (ESD), circularity, perimeter, etc.). The two software packages enable analysis of *in-situ* collected particles (see Fig. 1).



1. Size distribution of particles collected Gulf of Mexico, July, 2000. 10 m.

For the figure, the image extraction process was done manually, with minimum particle size allowed near 800 μm (the limit where absolute identification becomes more difficult). This manual extraction accounts for the artificial dropoff in counts at smaller ESD. Using automated image extraction software (in progress) will enable accurate counts.

ii. Dual Light Sheet (DLS-2)

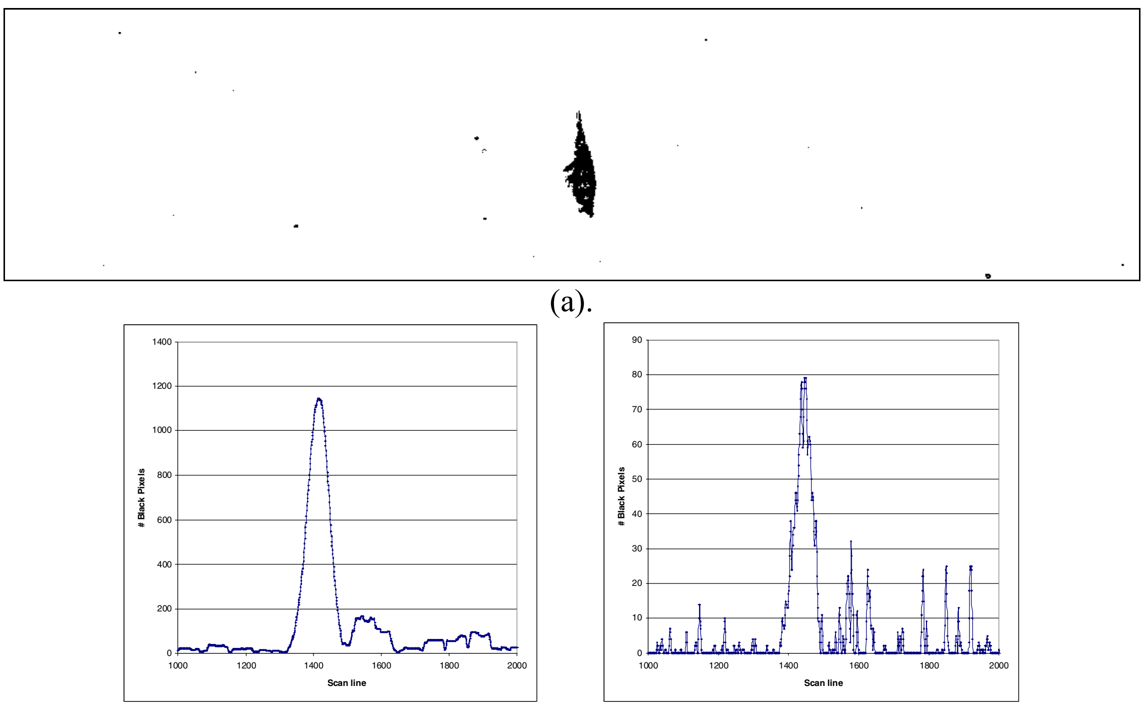
Particle concentration affects the transmission of light into water, which in turn will affect remote satellite imagery data and other measurements that rely on optical transmission. With the prototype DLS and Focal Technologies OPC [4], the measurement of particle size is based on attenuation of a wide (4 mm) light beam by a small opaque particle. The attenuated optical signal is amplified and sampled by a single electronic analog-to-digital conversion. Equivalent spherical diameter (ESD) is determined by the digital count caused by the particle, and is based on an empirical calibration using spherical beads. In reality, the orientation of the typical aspherical particle with respect to the light sheet width is unknown. If the particle is longer than the light sheet, it will be undersized. If it is much smaller than the beam width, then the particle is lost in noise. The digital sampling system also requires a relatively long minimum time (4 ms) between particles before the next one is sized, which may not represent actual conditions. Depending on the specific hydrodynamic properties of the sampling inlet and test platform, the volume of water sampled by any particle sizing instrument will vary from the amount of water passing through a similar cross section of water outside the instrument. Any calculation of particle density that uses an external flow meter or distance-over-ground measurement will misrepresent the water volume actually sampled. All of the above shortcomings contribute to inaccurate measurements of particle density.

The DLS-2 has been designed to address the shortcomings of the OPC and prototype DLS instrument. It has been developed to quickly measure a wide range of particle sizes, and non-invasively measure the internal flow rate of the sampled water. This yields a more accurate estimate of particle concentration.

A schematic of the DLS-2 instrument can be seen in the 2000-2001 proposal, and is briefly described. Light generated from an intensity stabilized semiconductor laser is collimated to produce a thin sheet of light. The light passes through the water, and is translated in the flow direction by 60 mm through an optically clear medium, and then again traverses the water column. The particle-attenuated optical signal passing a thin (300 μm) aperture is electronically amplified, digitized at 40 kHz, and integrated over the duration of the passing particle. Subsampling and integrating the particle yields an accurate area measurement, even when the particle is quite large or asymmetric. The likelihood of two particles being within a 300 μm section of water is much less than them being in a 4 mm cross section, so particle coincidence is reduced. Additionally, the digital signal at any moment is proportional to the width of the particle, not its area. Hence, the dynamic range required of the detector and electronics is reduced and signal-to-noise ratio is improved for the DLS-2 system. Particle velocity is determined from the particle transit time between the offset light sheets. Because there will be multiple particles between the light sheets constantly, the transit time is determined from the autocorrelation of the detected particle signal. A correlation maximum occurs at the mean particle transit time. A particle size histogram, velocity information, and system status and synchronization information are displayed and stored in real time on a shipboard PC.

The DLS-2 instrument was first deployed during the FLSE-3 (July, 2000 ECOHAB) cruise. Particle size and count were recorded, though the real-time *in-situ* velocity is still being tested. Small-scale deformations of the endcaps caused a depth-related laser beam deflection. This is compensated automatically in the instrument by digitally varying the internal gain before sampling. However, when deflection becomes sufficient, the gain could not fully compensate. Modifications to the system are currently being pursued.

An additional utility of having very clean, high-resolution SIPPER images available, is to predict the performance of attenuation-based particle-sizing instruments (eg. OPC and DLS-2). Coincidence and finite aperture size in the OPC can result in undercounting small particles, and improperly sizing large particles, even at relatively low particle count rates (<10 second^{-1}) [5]. SIPPER images frequently have multiple particles in the beam width at any given time, which supports the aforementioned findings. We have written software to simulate the electronic signals from both the OPC and DLS-2 instruments, based on actual SIPPER images. For example at 1 m s^{-1} water velocity, the 4 mm wide OPC window corresponds to 60 SIPPER scan lines; the DLS-2's 300 μm aperture corresponds to 4 scan lines. Summing the black pixels in the SIPPER image over the appropriate number of scan lines yields a simulated waveform for the OPC and DLS-2 instruments (Fig. 2).



(b) (c)

2. (a) SIPPER image of 7 mm long particle, (b) calculated OPC waveform (4 mm window), (c) calculated DLS-2 waveform (300 μm window).

It can be determined that the OPC would undersize the 7 mm long particle (2.5 mm ESD) by 23%, since it would never completely fit into the 4 mm aperture (though it would be sized more accurately if it had passed through the light sheet rotated 90°). The DLS-2, since it integrates the entire area within the copepod, sizes the particle to within a couple percent (reduced slightly by coincidence with small particles to the left of the copepod). Note that the smaller individual particles (near scan lines 1800-

1900) may be discerned in DLS-2 waveform, but are smeared together by the OPC, due to the OPC's wide aperture. This emphasizes the benefit of the current optical particle sizing instruments. The DLS-2 can yield both more accurate particle information and velocity in real-time, while the SIPPER instrument can be used for more accurate post analysis (identification, sizing and counting).

iii. HRS deployments

HRS testing and sampling was conducted in three locations in 2000: testing the new sensor configuration was conducted in Tampa Bay (20-21 Jun); HRS sampling was conducted during the FSLE-3 experiment (6-10 Jul) at the HyCODE/ECOHAB: Florida site; and, testing was conducted in the oceanic eastern Gulf of Mexico (23-26 Jul) to prove deepwater (200 m) capability of the new sensor system.

RESULTS

•Data gathered from HRS deployments provided information for HyCODE / ECOHAB models.

•Multiple-season optical and biological data gathered during field sampling indicated that a tight biophysical coupling exists between the two components, emphasizing the need for synoptic multisensor sampling.

•New optical techniques for recording suspended particles were modified and tested. With accompanying software, these allowed rapid assessment of particle distributions and classification.

•Field tests yielded valuable feedback, which permitted improvements in performance of optical sensors.

IMPACT/APPLICATIONS

This project represents a directed effort to build, test, and utilize systems for characterization of a wide variety of marine environments. Data gathered have direct application to predictive biological process models. The sensors being developed and tested are targeted for deployment on modern AUV's. Experience gained in deploying and developing sensors for AUV's will have significant impact on defining the appropriate tools for future automated monitoring of the ocean.

TRANSITIONS

The data output of this project will be of interest to programs such as HyCODE / ECOHAB. HRS data indicate that seawater optical properties at the HyCODE/ECOHAB: Florida site derive mainly from biotic activity (i.e. dissolved and particulate carbon) rather than sediment suspension processes. Others involved in the optical properties of water, and those creating biological - chemical - physical process linked models will use the data. Data gathered will also be used in optimization of AUV sensor deployments.

RELATED PROJECTS

Robert Byrne (USF) and his group have integrated their *in-situ* Spectroscopic Elemental Analysis System with the HRS platform during the July 2000 FSLE-3 deployments to better understand the correlation of nutrients (nitrite) with the variables measured with the HRS sensor suite.

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